hasty sketch of a few especially important formations that have been closely studied.

We pass over the oldest deposits, for the interpretation of which but few points of vantage present themselves, and we shall fix our attention on the upper half of the Carboniferous formation, the so-called Coal-measures. It has received this name because in many countries it contains those thick beds of fossil fuel which have become an indispensable factor of modern industries, and without which the actual status of our social and political condition could not have been attained. So great is the quantity of the fuel herein stored, that all that is furnished by other geological formations, taken together, falls far short of it. There is much difference of opinion as to the mode in which coal has been formed; but whatever disagreement there may be in matters of detail, this much is certain, that we have in coal the altered remains of a land-vegetation, which, partly at least, flourished in swamps. Of course the formation is not all or even chiefly coal; even where it is richest in coal, by far the greater part of the formation consists of shale, sandstone, and conglomerate, and the coal-beds are here and there interstratified, forming but a fraction of the total thickness. We may picture to ourselves the building up of the formation by supposing that a plain or depression was sometimes covered with water, sometimes dried up. When flooded, chiefly with fresh and but rarely with sea-water, beds of shale or sandstone were deposited; when dry, land or swamp plants sprang up, and their decayed remains furnished the material of coal. Then followed another period of inundation, and thick beds of shale, sandstone, and conglomerate were again deposited. . . . .

The vegetation that in its decay formed our beds of coal was of a peculiar character. As yet there existed no trees (with true foliage) and no flowering plants. A monotonous growth of plants with stiff leaves then clothed our continents. A great part in it was played by *Calamites*, great plants which no longer exist, and whose nearest relatives are the mares' tails so often met with in marshy ground; another important type was that of the *Lepidodendra*, large trees whose forked stems were covered with leaf scars arranged in a regular geometrical pattern, and the branches of which were clothed with short, stiff, grass-like leaves; and most important of all, the *Sigillarias*, the unbranching and twigless stems of which were marked with leaf scars in perpendicular rows and scale-like leaves. Both of these are long since extinct; and only the insignificant club-mosses of our present flora recall to us the varied gigantic forms of that distant age.

H. F. B.

(*To be continued.*)

LIGHTNING AND THE ELECTRIC SPARK.[1]

AT a date at least as remote as 600 years B.C. the Greek philosophers were acquainted with a curious little fact to which the modern science of electricity owes its name. They knew that a piece of amber (ἤλεκτρον) when rubbed against some suitable substance acquired a temporary attractive power, in virtue of which it became capable of lifting and holding light objects, such as dry leaves or pieces of straw. But another remarkable effect which often attends the friction of amber was for many centuries altogether overlooked. In A.D. 1708 it was first noticed by Dr. Wall that a piece of strongly excited amber emitted sparks, which were accompanied by crackling sounds, and these he had the sagacity to compare to thunder and lightning.

It must be confessed that the recognition of any resemblance between the microscopic scintillations thus produced and the brilliant lightning flash imposed a somewhat severe strain upon even the scientific imagination, and a few years later Stephen Gray, in reference to the same comparison, expressed the hope that "there might be found out a way to collect a greater quantity of the electric fire" than was then possible. His hope was realized by the subsequent improvement of electrical apparatus, and especially by the invention of the Leyden jar; and the effects obtainable by the means now at our command amply justify the speculations of Wall and Gray. The essential identity of the artificial electric spark with the natural lightning flash was conclusively established by the experiments of Franklin, and in these days it has become a mere common-place, familiar to everyone.

There are generally said to be two kinds of lightning flash, which are known as forked lightning and sheet lightning, the former being dangerous and destructive, the latter harmless. To these is sometimes added a third class, called ball lightning. The lightning flash of artists which is familiar to us from innumerable pictures, and of which the venomous-looking zigzag now projected upon the screen (copied from an engraving) is a fair example, has no existence in nature. It is simply an artistic fiction or symbol, like the conventional representation of a galloping horse, which, in the severe language of Mr. Muybridge, resembles nothing to be found in the heavens above or in the earth beneath. The absurdities commonly perpetrated in depicting animals in motion have been fully exposed by Mr. Muybridge with the assistance of photography. So, too, it is photography that has given the *coup de grâce* to the traditional forked lightning. Within the last few years an immense number of photographs of lightning flashes have been made. The Meteorological Society has formed a collection of these, containing about 200 examples, which, by the kindness of Mr. Marriott, the Secretary of the Society, I have had an opportunity of examining carefully. Not a single instance of the artistic lightning flash is to be found among them. The great majority bear a close resemblance to the sparks of our electrical machines: a few are distinguished by peculiarities which, though at first sight a little difficult to account for, can generally be explained and even imitated artificially.

What may be called a typical lightning flash is a stream of light which follows a sinuous and wavering course, very like that of a river as shown upon a map. [Several photographs of this kind of flash were exhibited by means of the lantern.] The next slide is a photograph of a machine-spark, about 3½ inches in length. The two kinds of discharge are so much alike in their general character that if it were not for the surroundings it would be hard to tell which was the lightning and which the artificial spark.

The variations upon the normal type of flash, which the Meteorological Society's photographs show, have been classified as ramified or branched lightning, beaded lightning, meandering or knotted lightning, ribbon lightning, and, lastly, dark lightning.

Branched lightning is again strikingly suggestive of a river in a map; not a simple stream, however, but one into which a number of tributaries flow. [Photographs were shown.] Sparks having branches of just the same character are easily produced by a large electrical machine. To obtain the effect well, the negative terminal should be made much larger than the positive, and the two should be separated so far that a spark will only just pass between them. According to Faraday, a ramified, or as he sometimes calls it a "brushy," spark occurs when the whole of the electricity has not been discharged, but only portions of it, more or less, according to circumstances. It is a "dilute" spark, generally passing to air or other badly conducting matter ("Exp. Res.," § 1448). When therefore a ramified flash occurs we may reasonably conclude that the discharge is partial and incomplete.

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[1] Extracted from a lecture on "Electrical Phenomena in Nature," delivered by Mr. Shelford Bidwell, F.R.S., at the London Institution on February 10, 1890.

In beaded lightning there occur a number of bright spots, giving the flash the appearance of an irregular string of lustrous beads. This phenomenon is sometimes well shown in photographs of the machine spark, especially when the quantity of electricity passing is increased by using very large Leyden jars. Under these circumstances the path of the discharge is often found to contain at irregular intervals certain small and abrupt V-shaped indentations, and these, especially when seen "end-on," appear to be more luminous than other portions of the flash. Probably, therefore, in a beaded flash the quantity of electricity passing is more than ordinarily great.

Sometimes a lightning flash appears to take a very circuitous and roundabout path, perhaps forming a nearly closed loop, or even a complete knot. Such is what the Thunderstorm Committee of the Meteorological Society have called "meandering" lightning. This remarkable effect is no doubt the result of an optical illusion, and occurs when the general direction of the flash (or of part of it) is either towards or away from the observer.

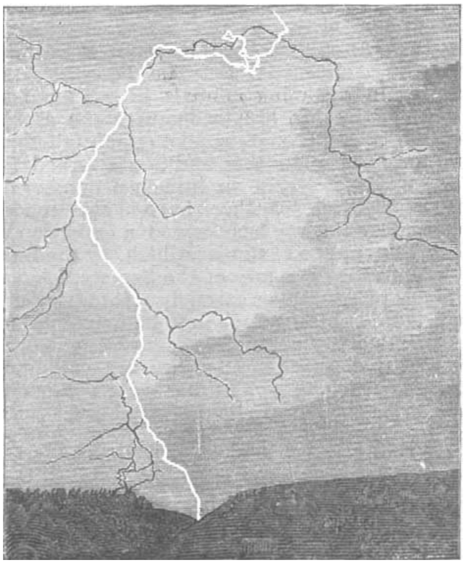

FIG. 1.

The different parts of the flash which seem to approach or to cross one another may in fact be miles apart. This explanation may be simply illustrated by means of the shadow of a properly bent wire. I have here a wire which is bent in such a form as to imitate a common type of flash or machine spark. When held transversely to the beam of the electric light its shadow is seen to represent fairly well the form of an ordinary sinuous flash; but if it is turned round so that its length is in the direction of the beam of light, the shadow presents an intricate appearance of loops and knots. Fig. 1 is from one of the most remarkable photographs of lightning flashes that I have seen. It was taken at Cambridge on June 6, 1889, by Mr. Rose, of Emmanuel College, and I am indebted for this copy to the kindness of Mr. W. N. Shaw, who described it at a recent meeting of the Physical Society. Among its many interesting features I will at present only direct your attention to the complicated knot which occurs in the upper part of the flash.

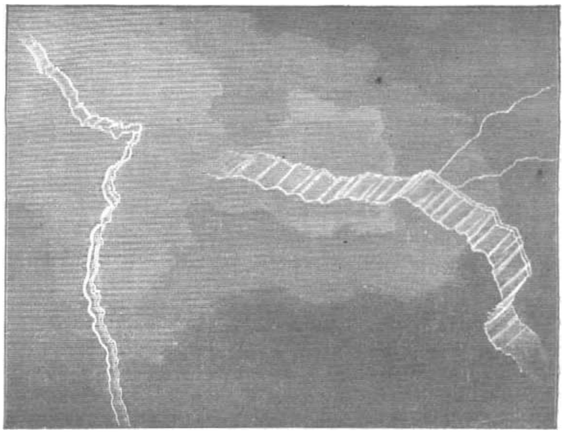

FIG. 2.

Many photographs of lightning have a curious flat and ribbon-like appearance. Such ribbons are sometimes broad and sometimes narrow. I have to thank Mr. Clayden for an excellent specimen of the broad kind, which was taken by himself last summer, and is reproduced in Fig. 2. The Thunderstorm Committee are of opinion that this peculiar structure may possibly not exist in nature at all, the effect being produced only in the photographic camera. It is noteworthy that, in nearly if not quite every case when broad ribbons have been obtained, the camera was held in the operator's hand, a fact which naturally suggests the idea that the widened image of the flash may be due to unsteadiness. It may be objected to this explanation that the duration of a lightning flash is so exceedingly brief as to preclude the possibility of any material movement during the time that its image is upon the sensitive plate. But such an objection is not unanswerable. It has often been observed that a lightning flash may be followed by one or more other flashes in rapid succession, all taking precisely the same path as the first. If then the camera were in motion a series of such flashes might impress themselves side by side upon the photographic plate, being so near together as to give the appearance of a single wide and flattened flash.[1] Moreover, though the true lightning flash is practically instantaneous it sometimes has a phosphorescent glow along its track, which lasts for at least a large fraction of a second. This phosphorescence would tend to connect the separate images into a uniform whole, and add to the ribbon-like appearance of the resulting picture. Dr. Hoffert has been kind enough to give me a copy of an exceptionally interesting photograph[2] which illustrates this explanation. The camera was held in the hand, and moved horizontally to and fro at the rate of about once in three-quarters of a second. The movement was continued until a flash was observed, when the lens was at once covered. The plate after development showed no less than two triple flashes and one double flash, eight in all, the whole of which, must have occurred, Dr. Hoffert thinks, within a little more than a second, forming a connected system of discharges which would appear to the eye as one. The several sets of flashes in the photograph are all joined together more or less perfectly by horizontal luminous streaks, which, though they may not impossibly represent a continuous brush-like discharge, are more probably due to phosphorescence of the oxygen of the air, oxygen, especially in the form of ozone, being a phosphorescent substance. If in taking Dr. Hoffert's photograph the camera had been moved slowly instead of quickly, I think it is clear that the appearance of one or more ribbon-like flashes, like those in Fig. 2, would have been produced.

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[1] It has been pointed out by Prof. S. P. Thompson that the path of the discharges might be shifted by the wind to a sufficient extent to produce the ribbon-like effect, even if the camera were perfectly steady.

[2] A good reproduction of this photograph is given in the *Phil. Mag.* (1889), and in the Proceedings of the Phys. Soc., vol. x. p. 176.

But the photograph of a flash may possibly assume a distinctly broadened form, perhaps more suggestive of a flattened wire than of a ribbon, when the camera is absolutely steady. In such cases it will generally (perhaps always) be seen that one edge of the image is sharp and clear, while the other is ill-defined and hazy. I have succeeded in imitating this effect very well in photographs of the machine spark: it is obtained when the light does not fall perpendicularly, or nearly so, upon the sensitive plate, and is no doubt due to successive reflections between the surfaces of the lens. [Exhibited.]

Lastly, we have to consider the so-called "dark flash." It occasionally happens that, on developing a photographic plate which has been exposed during a thunderstorm, the image of a lightning flash comes out black instead of white. Fig. 1 presents a striking instance of this phenomenon. Black ramifications are seen to proceed outwards on both sides of the main bright flash; there is also what appears to be an independent black flash which starts from the top of the picture and crosses the bright one near the knot. The origin of this strange appearance was for a long time a mystery. No one had ever seen a dark flash with the unassisted eye, and the question arose, whether the dark images in the photographs really represented a hitherto unobserved physical effect which occurred in the air itself, or whether, owing to some optical or chemical action taking place inside the camera or upon the sensitive plate, the impression of a luminous flash became converted into a dark one. There is no need to discuss the several ingenious hypotheses which were suggested in explanation of the anomaly; it is sufficient to say that the mystery was completely cleared up a few months ago by the experiments of Mr. Clayden. The fact, as demonstrated by him, is shortly this. If the lens of the camera be covered the moment after a flash has occurred, the developed image will always come out bright, feebly or strongly according to circumstances. If, however, the plate be exposed after a flash has acted upon it, either to the continued action of a feeble diffused light or to the powerful glare arising from one or more subsequent flashes, then on development the image of the original flash will probably come out black. The effect is therefore not a meteorological or physical one, but purely chemical. It can be obtained not only with a lightning flash, but also with a machine spark, or even with an ordinary flame. It is merely necessary that the plate should be exposed to the action of a certain amount of light after it has received the impression and before development.

Some photographs which I have made of machine sparks fully confirm this explanation of Mr. Clayden's. The room was illuminated by a single gas-jet, and the background was a white screen with a black post in the middle of it (see Fig. 3). Two series of sparks were passed between the ball terminals of an electrical machine and photographed. After the first series were taken, the lens was left uncovered for half a minute; then it was capped, the camera shifted slightly, and the second series taken; the lens was again left open for half a minute, and the plate afterwards removed from the camera and developed. It will be seen that while the second series of sparks come out bright in the natural way, the first series have been reversed and blackened by the action for one minute of the light reflected from the white screen upon the undeveloped image. Exposure to the diffused light for half a minute only was not in this case sufficient to cause reversal.

These experimental results make it almost certain that the flash in Fig. 1 was really a double one. The first flash was comparatively feeble, and possessed the lateral ramifications characteristic of an incomplete discharge. The second, which probably occurred immediately afterwards, was a powerful one without ramifications, and followed accurately the main path traced out by the other. The glare arising from this second discharge caused the photographic reversal of the ramifications belonging to the first.

Everyone must have noticed the proverbial quiver of a lightning flash. This peculiar effect is often due to the multiple discharge of which we have already spoken. Sometimes, however, I believe the phenomenon is a purely subjective one, depending upon a certain physiological reaction of the optic nerve. If we gaze at a bright flame which is suddenly uncovered and immediately extinguished, then after a very short interval of darkness a distinct but transient image of the flame will reappear; and it is even possible that after another brief interval a second after-image of the flame may be seen. It is, however, by no means easy to detect these appearances without considerable practice, because they belong to a class of impressions which we habitually train ourselves to disregard. But by means of a little device which I published a few years ago, the phenomenon may be easily demonstrated to almost anyone.

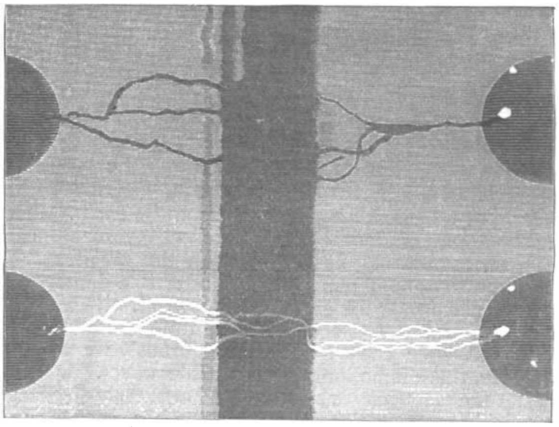

Fig. 3.

The beautiful effects produced by the rotation of a vacuum tube when illuminated by a series of discharges from an induction coil, are well known. The tube is generally attached to a horizontal axis, which is turned rapidly by means of a multiplying wheel; the images due to successive discharges, which, if the tube were at rest would be superposed, are thus caused to occupy different parts of the retina, and the result is the appearance of a gorgeous revolving star. But if the tube is caused to rotate very slowly, making about one turn in two or three seconds, there occurs a different and very curious phenomenon. The luminous images of the tube are almost superposed, forming a bunch which is slightly spread out at the ends. But about 40° behind the bunch, and separated from it by an interval of darkness, comes a ghost. This ghost is in shape and size an exact reproduction of the tube; it is very clearly defined, and is of a uniform bluish-grey tint. If the rotation is stopped, the ghost still moves slowly on, and after the lapse of about half a second disappears in coalescing with the luminous tube. The phenomenon of the ghost is clearly due to a succession of after-images, which are perceived a short time after the retina has been impressed by the flashes from the vacuum tube; and a similar physiological action, I think, explains—at least in some cases—the apparent reduplication of a flash of lightning.

Within the last year or two there has been a great deal of rather lively controversy concerning the protection of buildings from the destructive effects of lightning. The controversy originated in some lectures on lightning conductors, delivered by Prof. Oliver Lodge at the Society of Arts in 1888; it was continued at the Bath meeting of the British Association, and it culminated in a paper, also by Dr. Lodge, read last year at the Institution of Electrical Engineers, in which, after stating that "the old views on the subject of electrical conduction are hopelessly and absurdly and dangerously inadequate," the author expressed the opinion that it was "time that the prophets of the old superstition were slaughtered by the brook Kishon." In the animated discussion which followed, Dr. Lodge's views were ably opposed by Mr. Preece and others, and the question can hardly yet be considered as definitely settled. Time will not admit of an adequate review of the arguments which were employed on the two sides, but, considering its great practical importance, I think it will be of interest to give a very short statement of the matter in dispute, which I will illustrate by copies of Dr. Lodge's diagrams and apparatus.

Ever since the time of Franklin it has been customary to make use of long pointed metallic rods for the purpose of protecting important buildings from damage by lightning; and the "older electricians," as Dr. Lodge calls them, have always taught that, if the rod were well made, of sufficient size and height, and properly connected to earth, it afforded practically perfect security over a certain limited area. The function of the rod was supposed to be not so much to receive the shock of a lightning flash as to prevent a flash from occurring at all in the neighbourhood of the protected building: this it did by promoting the silent discharge of electricity between the cloud and the earth through the point of the rod.

The lower of these two tinfoil-covered boards represents the earth, and the upper one a cloud; the upright metal rod with a ball at the top of it is supposed to be a church, or other building, erected upon the earth. Charging the apparatus by means of the electrical machine, we get a series of strong flashes between the cloud and the church, every one of which might do terrible damage. If now we place near the church another rod, with a needle-point at its end, to serve as a lightning-conductor, the flashes at once cease: however vigorously we work the machine, there is no longer any visible effect. The fact is, that the electricity is silently and harmlessly discharged as quickly as it is generated. In such a case as is at present represented by the model, the efficacy of a lightning conductor would be complete. This is what Dr. Lodge calls the case of "steady strain," and is that indicated in his first diagram [exhibited], where the charged cloud above the church spire is supposed to have moved into its present threatening position from a distance. According to Dr. Lodge, this is the only kind of lightning discharge which was ever contemplated by the older electricians.

But suppose that a harmless uncharged cloud which might be hovering over the church were suddenly to receive an overflowing charge of electricity by a flash from another more distant cloud. There would then be no time for any gradual relief of the strain by a silent discharge through the lightning conductor, and either the conductor itself or the church would infallibly be struck by a flash from the overflowing cloud.

By altering the connections between the model and the electrical machine,[1] we can easily imitate this condition of things. The tinfoil-covered boards now remain absolutely uncharged until the moment when there is a spark between the terminals of the machine: then they are suddenly charged, and a flash instantly passes between the cloud and the church. Placing the needle-pointed lightning conductor beside the church, we now find that it is powerless to prevent the flashes: they go on just as rapidly as before, striking either the conductor or the church, or sometimes both at once. This case, which, I think, Dr. Lodge was undoubtedly the first to call attention to explicitly in connection with thunderstorms, is called by him the case of "impulsive rush." The occurrence of an "impulsive-rush" flash, then, cannot be warded off by a lightning conductor. The most that a conductor can do is to divert the main shock of the discharge from the building to itself. But even so the lightning may do considerable damage, for, as Dr. Lodge says, "it is hopeless to pretend to be able to make the lightning conductor so much the easiest path that all others are protected. All possible paths will share the discharge between them, and lots of apparently impossible ones." Moreover, not only is the lightning conductor itself, when struck, liable to spit off sparks laterally, however good its earth connection may be, but other metallic bodies in the neighbourhood may do the same, whether such bodies are insulated or not.

The moral appears to be this. In all cases of steady strain in which a charged cloud descending from the upper regions of the air, or approaching from a distance, might inflict serious injury upon an unprotected building, a well-designed and properly earth-connected lightning-rod is an absolute safeguard. In a case of "impulsive rush," the rod may often be of use in bearing the brunt of the discharge, though sometimes the lightning will take no notice whatever of it, striking the building and altogether neglecting the rod; and it is even possible that a high rod might attract a destructive discharge which otherwise would not have occurred at all. Although, therefore, a lightning-rod is in many cases, probably in a very large majority, of the greatest service, it cannot be depended upon as affording perfect immunity from risk; and the assumption which has universally been made by the "older electricians," that damage by lightning is in itself conclusive evidence of some imperfection in the conductor, is an unfounded one.

In conclusion, it may not be out of place to say a word or two on the subject of personal danger from lightning. The spectacle of a severe thunderstorm, magnificent as it is, is no doubt calculated to inspire a certain amount of alarm. But statistics show clearly enough that, at least in this country, its bark is worse than its bite. It appears, from a paper published last year by Inspector-General Lawson, that the number of deaths caused by lightning in England and Wales from 1852 to 1880, as recorded in the returns of the Registrar-General, were 546, or rather less than 19 per annum. The average population during that period may be taken as 22 millions; it follows, therefore, that the average annual death-rate from lightning was considerably below 1 per million of the population. The risk of a fatal lightning stroke in any individual case is therefore exceedingly small.

SPORTS.[1]

IT is highly desirable that we should attach a definite signification to this word. Among gardeners it may mean many things, whilst, among botanists, it is restricted to cases of bud-variation as distinguished from variation from seed. In this note we shall use the word in its botanical sense, as applying to a special illustration of that tendency to vary which is common to all living beings. We shall, however, gain a clearer idea of what true sports are by the elimination of certain things which are not sports, though often called so. In the first place they are not seedling variations. Out of a hundred seeds of Lawson's Cypress that are sown it is possible, I suppose,

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[1] The tinfoil-covered boards were connected with the outer coatings of the Leyden jars, their inner coatings being in connection with the terminals of the machine.

[1] Reprinted from *Garden and Forest*. The article contains the substance of an unwritten address lately given to a society of gardeners.